HONORS PHYSICS
WAVES HOMEWORK SOLUTIONS

ASSIGNMENT #1

Q13 The speed of the transverse wave is measuring how fast the wave disturbance moves along the cord. For a uniform cord, that speed is constant, and depends on the tension in the cord and the mass density of the cord. The speed of a tiny piece of the cord is measuring how fast the piece of cord moves perpendicularly to the cord, as the disturbance passes by. That speed is not constant — if a sinusoidal wave is traveling on the cord, the speed of each piece of the cord will be given by the speed relationship of a simple harmonic oscillator (Equation 11-9), which depends on the amplitude of the wave, the frequency of the wave, and the specific time of observation.

Q15 If you strike the horizontal rod vertically, you will create primarily transverse waves. If you strike the rod parallel to its length, you will create primarily longitudinal waves.

P36 The wave speed is given by \( v = \lambda f \). The period is 3.0 seconds, and the wavelength is 6.5 m.

\[
v = \lambda f = \lambda / T = (6.5 \text{ m}) / (3.0 \text{ s}) = 2.16 \text{ m/s}
\]

P38 To find the wavelength, use \( \lambda = v / f \).

AM: \[
\lambda_1 = \frac{v}{f_1} = \frac{3.0 \times 10^8 \text{ m/s}}{550 \times 10^3 \text{ Hz}} = 545 \text{ m}
\]

AM: 188 m to 545 m

\[
\lambda_2 = \frac{v}{f_2} = \frac{3.0 \times 10^8 \text{ m/s}}{1600 \times 10^7 \text{ Hz}} = 188 \text{ m}
\]

FM: 2.78 m to 3.41 m

FM: \[
\lambda_1 = \frac{v}{f_1} = \frac{3.0 \times 10^8 \text{ m/s}}{88.0 \times 10^6 \text{ Hz}} = 3.41 \text{ m}
\]

FM: \[
\lambda_2 = \frac{v}{f_2} = \frac{3.0 \times 10^8 \text{ m/s}}{108 \times 10^6 \text{ Hz}} = 2.78 \text{ m}
\]

P43 The speed of the water wave is given by \( v = \sqrt{B/\rho} \), where \( B \) is the bulk modulus of water, from Table 9-1, and \( \rho \) is the density of sea water, from Table 10-1. The wave travels twice the depth of the ocean during the elapsed time.

\[
v = \frac{2L}{t} \rightarrow L = \frac{vt}{2} = \frac{3.0 \text{ s}}{2} \sqrt{\frac{B}{\rho}} = \frac{3.0}{2} \sqrt{\frac{2.0 \times 10^9 \text{ N/m}^2}{1.025 \times 10^3 \text{ kg/m}^3}} = 2.10 \times 10^4 \text{ m}
\]
Both waves travel the same distance, so $\Delta x = v_1 t_1 = v_2 t_2$. We let the smaller speed be $v_1$, and the larger speed be $v_2$. The slower wave will take longer to arrive, and so $t_1$ is more than $t_2$.

$$t_1 = t_2 + 2.0 \text{ min} = t_2 + 120 \text{ s} \quad \rightarrow \quad v_1 (t_2 + 120 \text{ s}) = v_2 t_2 \quad \rightarrow$$

$$t_2 = \frac{v_1}{v_2 - v_1} (120 \text{ s}) = \frac{5.5 \text{ km/s}}{8.5 \text{ km/s} - 5.5 \text{ km/s}} (120 \text{ s}) = 220 \text{ s}$$

$$\Delta x = v_2 t_2 = (8.5 \text{ km/s})(220 \text{ s}) = 1.9 \times 10^3 \text{ km}$$

(b) This is not enough information to determine the epicenter. All that is known is the distance of the epicenter from the seismic station. The direction is not known, so the epicenter lies on a circle of radius $1.9 \times 10^3 \text{ km}$ from the seismic station. Readings from at least two other seismic stations are needed to determine the epicenter’s position.

ASSIGNMENT #2

Q17 (a) Similar to the discussion in section 11-9 for spherical waves, as a circular wave expands, the circumference of the wave increases. For the energy in the wave to be conserved, as the circumference increases, the intensity has to decrease. The intensity of the wave is proportional to the square of the amplitude

(b) The water waves will decrease in amplitude due to dissipation of energy from viscosity in the water (dissipative or frictional energy loss).

Q19 The frequency must stay the same because the media is continuous — the end of one section of cord is physically tied to the other section of cord. If the end of the first section of cord is vibrating up and down with a given frequency, then since it is attached to the other section of cord, the other section must vibrate at the same frequency. If the two pieces of cord did not move at the same frequency, they would not stay connected, and then the waves would not pass from one section to another.

Q22 A major distinction between energy transfer by particles and energy transfer by waves is that particles must travel in a straight line from one place to another in order to transfer energy, but waves can diffract around obstacles. For instance, sound can be heard around a corner, while you cannot throw a ball around a corner. So if a barrier is placed between the source of the energy and the location where the energy is being received, and energy is still received in spite of the barrier, it is a good indication that the energy is being carried by waves. If the placement of the barrier stops the energy transfer, it could be that the energy transfer is being carried out by particles. It could also be that the energy transfer is being carried out with waves whose wavelength is much smaller than the dimensions of the barrier.
(c) The energy is all kinetic energy at the moment when the string has no displacement. There is no elastic potential energy at that moment. Each piece of the string has speed but no displacement.

P67 The unusual decrease of water corresponds to a trough in Figure 11-24. The crest or peak of the wave is then one-half wavelength distant. The peak is 125 km away, traveling at 750 km/hr.

\[ \Delta x = vt \rightarrow t = \frac{\Delta x}{v} = \frac{125 \text{ km}}{750 \text{ km/hr}} \left( \frac{60 \text{ min}}{1 \text{ hr}} \right) = 10 \text{ min} \]

ASSIGNMENT #3

Q1 Sound exhibits several phenomena that give evidence that it is a wave. The phenomenon of interference is a wave phenomenon, and sound produces interference (such as beats). The phenomenon of diffraction is a wave phenomenon, and sound can be diffracted (such as sound being heard around corners). Refraction is a wave phenomenon, and sound exhibits refraction when passing obliquely from one medium to another.

Q3 The child speaking into a cup creates sound waves which cause the bottom of the cup to vibrate. Since the string is tightly attached to the bottom of the cup, the vibrations of the cup are transmitted to longitudinal waves in the string. These longitudinal waves travel down the string, and cause the bottom of the receiver cup to vibrate. This relatively large vibrating surface moves the adjacent air, and generates sound waves from the bottom of the cup, traveling up into the cup. These waves are incident on the receiver’s ear, and they hear the sound from the speaker.

P3 (a) \[ \lambda_{20 \text{ Hz}} = \frac{v}{f} = \frac{343 \text{ m/s}}{20 \text{ Hz}} = 17.2 \text{ m} \]

So the range is from 17.2 cm to 17.2 m.

(b) \[ \lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1 \times 10^6 \text{ Hz}} = 3.43 \times 10^{-5} \text{ m} \]
For the fish, the speed of sound in seawater must be used (given in Table 12-1).

\[ d = vt \quad \rightarrow \quad t = \frac{d}{v} = \frac{1.0 \times 10^3 \text{ m}}{1560 \text{ m/s}} = 0.641 \text{ s} \]

For the fishermen, the speed of sound in air must be used.

\[ d = vt \quad \rightarrow \quad t = \frac{d}{v} = \frac{1.0 \times 10^3 \text{ m}}{345 \text{ m/s}} = 2.90 \text{ s} \]

The “5 second rule” says that for every 5 seconds between seeing a lightning strike and hearing the associated sound, the lightning is 1 mile distant. We assume that there are 5 seconds between seeing the lightning and hearing the sound.

(a) At 30°C, the speed of sound is \[331 + 0.60(30)\] m/s = 349 m/s. The “experimental” distance to the lightning is therefore \[d = vt = (349 \text{ m/s})(5 \text{ s}) = 1745 \text{ m} \]. A known mile is 1609 m.

\[
\% \text{ error} = \left| \frac{1609 - 1745}{1609} \right| \times 100 = 8.45\%
\]

(b) At 10°C, the speed of sound is \[331 + 0.60(10)\] m/s = 337 m/s. The “experimental” distance to the lightning is therefore \[d = vt = (337 \text{ m/s})(5 \text{ s}) = 1685 \text{ m} \]. A known mile is 1609 m.

\[
\% \text{ error} = \left| \frac{1609 - 1685}{1609} \right| \times 100 = 4.72\%
\]

**ASSIGNMENT #4**

Q17 The highest frequency of sound will be heard at position C, while the child is swinging forward. Assuming the child is moving with SHM, then the highest speed is at the equilibrium point, point C. And to have an increased pitch, the relative motion of the source and detector must be towards each other. The child would also hear the lowest frequency of sound at point C, while swinging backwards.

P49 (a) Observer moving towards stationary source.

\[ f_o = f_s \left( \frac{v + v_o}{v \mp v_s} \right) = (1550 \text{ Hz}) \left( \frac{345 + 30}{345} \right) = 1685 \text{ Hz} \]

(b) Observer moving away from stationary source.

\[ f_o = f_s \left( \frac{v + v_o}{v \mp v_s} \right) = (1550 \text{ Hz}) \left( \frac{345 - 30}{345} \right) = 1415 \text{ Hz} \]
P50 (a) Source moving towards stationary observer.

\[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (1550 \text{ Hz}) \left( \frac{345}{345 - 32} \right) = 1708 \text{ Hz} \]

(b) Source moving away from stationary observer.

\[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (1550 \text{ Hz}) \left( \frac{345}{345 + 32} \right) = 1418 \text{ Hz} \]

P51 (a) For the 15 m/s relative velocity:

source moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345}{345 - 15} \right) = 2091 \text{ Hz} \]

observer moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345 + 15}{345} \right) = 2087 \text{ Hz} \]

The frequency shifts are slightly different, with \( f_{\text{source moving}} > f_{\text{observer moving}} \). The two frequencies are close, but they are not identical. To 3 significant figures they are the same.

(b) For the 150 m/s relative velocity:

source moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345}{345 - 150} \right) = 3.54 \times 10^3 \text{ Hz} \]

observer moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345 + 150}{345} \right) = 2.87 \times 10^3 \text{ Hz} \]

The difference in the frequency shifts is much larger this time, still with \( f_{\text{source moving}} > f_{\text{observer moving}} \).

(c) For the 300 m/s relative velocity:

source moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345}{345 - 300} \right) = 15.3 \times 10^3 \text{ Hz} \]

observer moving: \[ f_o = f_s \left( \frac{v \pm v_o}{v \mp v_s} \right) = (2000 \text{ Hz}) \left( \frac{345 + 300}{345} \right) = 3.74 \times 10^3 \text{ Hz} \]

The difference in the frequency shifts is quite large, still with \( f_{\text{source moving}} > f_{\text{observer moving}} \).

The Doppler formulas are asymmetric, with a larger shift for the moving source than for the moving observer, when the two are getting closer to each other. As the source moves toward the observer with speeds approaching the speed of sound, the observed frequency tends towards infinity. As the observer moves toward the source with speeds approaching the speed of sound, the observed frequency tends towards twice the emitted frequency.
The moving object can be treated as a moving “observer” for calculating the frequency it receives and reflects. The bat (the source) is stationary, while the “observer” is receding.

\[ f_{\text{object}} = f_{\text{bat}} \left( \frac{v_{\text{sound}} - v_{\text{object}}}{v_{\text{sound}}} \right) \]

Then the object can be treated as a moving “source”, emitting the frequency \( f_{\text{object}} \). The bat is a stationary observer, while the object is a receding “source”.

\[ f_{\text{bat,final}} = f_{\text{object}} \left( \frac{v_{\text{sound}}}{v_{\text{sound}} + v_{\text{object}}} \right) = f_{\text{bat}} \left( \frac{v_{\text{sound}}}{v_{\text{sound}} + v_{\text{object}}} \right) \cdot f_{\text{object}} \left( \frac{v_{\text{sound}} - v_{\text{object}}}{v_{\text{sound}}} \right) = f_{\text{bat}} \left( \frac{v_{\text{sound}} - v_{\text{object}}}{v_{\text{sound}} + v_{\text{object}}} \right) \]

\[ = \left( 5.00 \times 10^4 \text{ Hz} \right) \frac{345 \text{ m/s} - 25.0 \text{ m/s}}{345 \text{ m/s} + 25.0 \text{ m/s}} = 4.32 \times 10^4 \text{ Hz} \]

As the train approaches, the observed frequency is given by \( f_{o1} = f_s \left( \frac{v}{v - v_s} \right) \). As the train recedes, the observed frequency is given by \( f_{o2} = f_s \left( \frac{v}{v + v_s} \right) \). Solve each expression for \( f_s \), equate them, and then solve for \( v_s \).

\[ f_{o1} \left( \frac{v - v_s}{v} \right) = f_{o2} \left( \frac{v + v_s}{v} \right) \rightarrow f_{o1}v - f_{o1}v_s = f_{o2}v + f_{o2}v_s \]

\[ v_s = v \left( \frac{f_{o1} - f_{o2}}{f_{o1} + f_{o2}} \right) = \left( 345 \text{ m/s} \right) \frac{(538 \text{ Hz} - 486 \text{ Hz})}{(538 \text{ Hz} + 486 \text{ Hz})} = 17.5 \text{ m/s} \]

**ASSIGNMENT #5**

**P8**

120 dB = 10 log \( \frac{I_{120}}{I_0} \) \rightarrow \( I_{120} = 10^{12} I_0 = 10^{12} \left( 1.0 \times 10^{-12} \text{ W/m}^2 \right) = 1.0 \text{ W/m}^2 \)

20 dB = 10 log \( \frac{I_{20}}{I_0} \) \rightarrow \( I_{20} = 10^2 I_0 = 10^2 \left( 1.0 \times 10^{-12} \text{ W/m}^2 \right) = 1.0 \times 10^{-10} \text{ W/m}^2 \)

The pain level is \( 10^{10} \) (ten billion!) times more intense than the whisper.

**P9**

\[ \beta = 10 \log \frac{I}{I_0} = 10 \log \frac{2.0 \times 10^{-6} \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2} = 63 \text{ dB} \]
According to Table 12-2, the intensity in normal conversation, when about 50 cm from the speaker, is about $3 \times 10^{-6} \text{ W/m}^2$. The intensity is the power output per unit area, and so the power output can be found. The area is that of a sphere.

\[ I = \frac{P}{A} \quad \Rightarrow \quad P = IA = I \left( 4\pi r^2 \right) = \left( 3 \times 10^{-6} \text{ W/m}^2 \right) 4\pi (0.50 \text{ m})^2 = 9.425 \times 10^{-6} \text{ W} \]

(b) \[ 100 \text{ W} \left( \frac{1 \text{ person}}{9.425 \times 10^{-6} \text{ W}} \right) = 1.06 \times 10^7 \approx 1 \times 10^7 \text{ people} \]

or \[ I = \frac{100}{4\pi(0.5)^2} = 31.8 \text{ W/m}^2 \Rightarrow \frac{31.8 \text{ W/m}^2}{3.0 \times 10^6 \text{ W/m}^2} = 1.06 \times 10^7 \text{ people} \]

The intensity of the sound is defined to be the power per unit area. We assume that the sound spreads out spherically from the loudspeaker.

(a)

\[ I_{250} = \frac{250 \text{ W}}{4\pi (3.5 \text{ m})^2} = 1.6 \text{ W/m}^2 \quad \beta_{250} = 10 \log \frac{I_{250}}{I_0} = 10 \log \frac{1.6 \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2} = 122 \text{ dB} \]

\[ I_{40} = \frac{40 \text{ W}}{4\pi (3.5 \text{ m})^2} = 0.26 \text{ W/m}^2 \quad \beta_{40} = 10 \log \frac{I_{40}}{I_0} = 10 \log \frac{0.26 \text{ W/m}^2}{1.0 \times 10^{-12} \text{ W/m}^2} = 114 \text{ dB} \]

(b) According to the textbook, for a sound to be perceived as twice as loud as another means that the intensities need to differ by a factor of 10. That is not the case here – they differ only by a factor of \( \frac{1.6}{0.26} \approx 6 \). The expensive amp will not sound twice as loud as the cheaper one.

From Figure 12-6, a 100-Hz tone at 50 dB has a loudness of about 20 phons. At 6000 Hz, 20 phons corresponds to about 25 dB. Answers may vary due to estimation in the reading of the graph.

From Figure 12-6, at 30 dB the low frequency threshold of hearing is about 150 Hz. There is no intersection of the threshold of hearing with the 30 dB level on the high frequency side of the chart, and so a 30 dB signal can be heard all the way up to the highest frequency that a human can hear, 20,000 Hz.
ASSIGNMENT #6

Q9 To make the water “slosh”, you must shake the water (and the pan) at the natural frequency for water waves in the pan. The water then is in resonance, or in a standing wave pattern, and the amplitude of oscillation gets large. That natural frequency is determined by the size of the pan — smaller pans will slosh at higher frequencies, corresponding to shorter wavelengths for the standing waves. The period of the shaking must be the same as the time it takes a water wave to make a “round trip” in the pan.

Q10 Some examples of resonance:

Pushing a child on a playground swing — you always push at the frequency of the swing.

Seeing a stop sign oscillating back and forth on a windy day.

When singing in the shower, certain notes will sound much louder than others.

Utility lines along the roadside can have a large amplitude due to the wind.

Rubbing your finger on a wineglass and making it “sing”.

Blowing across the top of a bottle.

A rattle in a car (see Question 11).

P53 The fundamental frequency of the full string is given by \( f_{\text{unfingered}} = \frac{v}{2L} = 294 \text{ Hz} \). If the length is reduced to 2/3 of its current value, and the velocity of waves on the string is not changed, then the new frequency will be

\[
f_{\text{fingered}} = \frac{v}{2\left(\frac{2}{3}L\right)} = \frac{3}{2} \frac{v}{2L} = \left(\frac{3}{2}\right)f_{\text{unfingered}} = \left(\frac{3}{2}\right)294 \text{ Hz} = 441 \text{ Hz}
\]

P54 Four loops is the standing wave pattern for the 4\(^{th}\) harmonic, with a frequency given by \( f_4 = 4f_1 = 280 \text{ Hz} \). Thus \( f_1 = 70 \text{ Hz}, f_2 = 140 \text{ Hz}, f_3 = 210 \text{ Hz} \) and \( f_5 = 350 \text{ Hz} \) are all other resonant frequencies.

P55 Adjacent nodes are separated by a half-wavelength, as examination of Figure 11-40 will show.

\[
\lambda = \frac{v}{f} \quad \Rightarrow \quad \Delta x_{\text{node}} = \frac{1}{2}\lambda = \frac{v}{2f} = \frac{92 \text{ m/s}}{2(475 \text{ Hz})} = 9.68 \times 10^{-2} \text{ m}
\]
The string must vibrate in a standing wave pattern to have a certain number of loops. The frequency of the standing waves will all be 60 Hz, the same as the vibrator. That frequency is also expressed by Equation (11-19b), \( f_n = \frac{n v}{2L} \). The speed of waves on the string is given by Equation (11-13),
\[
v = \sqrt{\frac{F_T}{m/L}}.
\]
The tension in the string will be the same as the weight of the masses hung from the end of the string, \( F_T = mg \). Combining these relationships gives an expression for the masses hung from the end of the string.

\[
f_n = \frac{nv}{2L} = \frac{n}{2L} \sqrt{\frac{F_T}{m/L}} = \frac{n}{2L} \sqrt{\frac{mg}{(m/L)}} \quad \rightarrow \quad m = \frac{4L^2 f_n^2 (m/L)}{n^2 g}
\]
\[
m_1 = \frac{4(1.50 \text{ m})^2 (60 \text{ Hz})^2 (3.9 \times 10^{-4} \text{ kg/m})}{1^2 (9.80 \text{ m/s}^2)} = 1.289 \text{ kg}
\]
\[
(b) \quad m_2 = \frac{m_1}{2^2} = \frac{1.289 \text{ kg}}{4} = 0.322 \text{ kg}
\]
\[
(c) \quad m_5 = \frac{m_1}{5^2} = \frac{1.289 \text{ kg}}{25} = 5.16 \times 10^{-2} \text{ kg}
\]

**ASSIGNMENT #7**

**Q9** For a string with fixed ends, the fundamental frequency is given by \( f = \frac{v}{2L} \) and so the length of string for a given frequency is \( L = \frac{v}{2f} \). For a string, if the tension is not changed while fretting, the speed of sound waves will be constant. Thus for two frequencies \( f_1 < f_2 \), the spacing between the frets corresponding to those frequencies is given as follows.

\[
L_1 - L_2 = \frac{v}{2f_1} - \frac{v}{2f_2} = \frac{v}{2} \left( \frac{1}{f_1} - \frac{1}{f_2} \right)
\]

Now see table 12-3. Each note there would correspond to one fret on the guitar neck. Notice that as the adjacent frequencies get higher, the inter-frequency spacing also increases. The change from C to C# is 15 Hz, while the change from G to G# is 23 Hz. Thus their reciprocals get closer together, and so from the above formula, the length spacing gets closer together. Consider a numeric example.

\[
L_C - L_{Cs} = \frac{v}{2} \left( \frac{1}{262} - \frac{1}{277} \right) = \frac{v}{2} (2.07 \times 10^{-4})
\]
\[
L_G - L_{Gs} = \frac{v}{2} \left( \frac{1}{392} - \frac{1}{415} \right) = \frac{v}{2} (1.41 \times 10^{-4})
\]
\[
\frac{L_G - L_{Gs}}{L_C - L_{Cs}} = 0.684
\]
The G to G# spacing is only about 68% of the C to C# spacing.
For a vibrating string, the frequency of the fundamental mode is given by $f = \frac{v}{2L} = \frac{1}{2L} \sqrt{\frac{F_t}{m/2L}}$.

$$f = \frac{1}{2L} \sqrt{\frac{F_t}{m/L}} \quad \rightarrow \quad F_t = 4Lf^2m = 4(0.32\ m)(440\ Hz)^2 (3.5 \times 10^{-4}\ kg) = 8.67\ N$$

For a fixed string, the frequency of the $n^{th}$ harmonic is given by $f_n = nf_1$. Thus the fundamental for this string is $f_1 = f_3/3 = 540\ Hz/3 = 180\ Hz$. When the string is fingered, it has a new length of 60% of the original length. The fundamental frequency of the vibrating string is also given by $f_1 = \frac{v}{2L}$, and $v$ is a constant for the string, assuming its tension is not changed.

$$f_{\text{fingered}} = \frac{v}{2L_{\text{fingered}}} = \frac{v}{2(0.60)L} = \frac{1}{0.60} f_1 = \frac{180\ Hz}{0.60} = 300\ Hz$$

(a) We assume that the speed of waves on the guitar string does not change when the string is fretted. The fundamental frequency is given by $f = \frac{v}{2L}$, and so the frequency is inversely proportional to the length.

$$f \propto \frac{1}{L} \quad \rightarrow \quad fL = \text{constant}$$

$$f_L E = f_L A \quad \rightarrow \quad L_A = L_E \frac{f_L}{f_A} = (0.73\ m) \left(\frac{330\ Hz}{440\ Hz}\right) = 0.5475\ m$$

The string should be fretted a distance $0.73\ m - 0.5475\ m = 0.1825\ m$ from the nut of the guitar.

(b) The string is fixed at both ends and is vibrating in its fundamental mode. Thus the wavelength is twice the length of the string (see Fig. 12-7).

$$\lambda = 2L = 2(0.5475\ m) = 1.095\ m$$

(c) The frequency of the sound will be the same as that of the string, $440\ Hz$. The wavelength is given by the following.

$$\lambda = \frac{v}{f} = \frac{343\ m/s}{440\ Hz} = 0.780\ m$$
Call the frequencies of four strings of the violin \( f_A, f_B, f_C, f_D \) with \( f_A \) the lowest pitch. The mass per unit length will be named \( \mu \). All strings are the same length and have the same tension. For a string with both ends fixed, the fundamental frequency is given by \( f_1 = \frac{v}{2L} = \frac{1}{2L} \sqrt{\frac{F_T}{\mu}} \).

\[
\begin{align*}
\frac{F_T}{\mu_B} &= \frac{1}{2L} \mu_A \rightarrow f_B &= 1.5 f_A \\
\frac{F_T}{\mu_C} &= (1.5)^2 \frac{1}{2L} \mu_A \rightarrow f_C &= 1.5^2 f_A \\
\frac{F_T}{\mu_D} &= (1.5)^3 \frac{1}{2L} \mu_A \rightarrow f_D &= 1.5^3 f_A
\end{align*}
\]

\[\mu_B = \frac{\mu_A}{(1.5)^4} = 0.44 \mu_A\]
\[\mu_C = \frac{\mu_A}{(1.5)^6} = 0.20 \mu_A\]
\[\mu_D = \frac{\mu_A}{(1.5)^8} = 0.088 \mu_A\]

ASSIGNMENT #8

Q7 The basic equation determining the pitch of the organ pipe is either \( f_{\text{closed}} = \frac{nv}{4L}, n = \text{odd integer}, \) for a closed pipe, or \( f_{\text{open}} = \frac{nv}{2L}, n = \text{integer}, \) for an open pipe. In each case, the frequency is proportional to the speed of sound in air. Since the speed is a function of temperature, and the length of any particular pipe is fixed, the frequency is also a function of temperature. Thus when the temperature changes, the resonant frequencies of the organ pipes change as well. Since the speed of sound increases with temperature, as the temperature increases, the pitch of the pipes increases as well.

P25 (a) If the pipe is closed at one end, only the odd harmonic frequencies are present, and are given by \( f_n = \frac{nv}{4L} = nf_i, n = 1, 3, 5 \ldots \).

\[
\begin{align*}
f_i &= \frac{v}{4L} = \frac{343 \text{ m/s}}{4(1.12 \text{ m})} = 76.6 \text{ Hz} \\
f_3 &= 3f_i = \boxed{230 \text{ Hz}} \quad f_5 &= 5f_i = \boxed{383 \text{ Hz}} \quad f_7 &= 7f_i = \boxed{536 \text{ Hz}}
\end{align*}
\]

(b) If the pipe is open at both ends, all the harmonic frequencies are present, and are given by \( f_n = \frac{nv}{2L} = nf_i \).

\[
\begin{align*}
f_i &= \frac{v}{2L} = \frac{343 \text{ m/s}}{2(1.12 \text{ m})} = 153 \text{ Hz} \\
f_2 &= 2f_i = \boxed{306 \text{ Hz}} \quad f_3 &= 3f_i = \boxed{459 \text{ Hz}} \quad f_4 &= 4f_i = \boxed{612 \text{ Hz}}
\end{align*}
\]
P27  For a pipe open at both ends, the fundamental frequency is given by \( f_1 = \frac{v}{2L} \), and so the length for a given fundamental frequency is \( L = \frac{v}{2f_1} \).

\[
L_{20 \text{ Hz}} = \frac{343 \text{ m/s}}{2(20 \text{ Hz})} = 8.6 \text{ m} \\
L_{20 \text{ kHz}} = \frac{343 \text{ m/s}}{2(20,000 \text{ Hz})} = 8.6 \times 10^{-3} \text{ m}
\]

P33  (a)  At \( T = 20^\circ C \), the speed of sound is 343 m/s. For an open pipe, the fundamental frequency is given by \( f = \frac{v}{2L} \).

\[
f = \frac{v}{2L} \rightarrow L = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(294 \text{ Hz})} = 0.583 \text{ m}
\]

(b)  The speed of sound in helium is 1005 m/s, from Table 12-1. Use this and the pipe’s length to find the pipe’s fundamental frequency.

\[
f = \frac{v}{2L} = \frac{1005 \text{ m/s}}{2(0.583 \text{ m})} = 862 \text{ Hz}
\]

P34  (a)  The difference between successive overtones for this pipe is 176 Hz. The difference between successive overtones for an open pipe is the fundamental frequency, and each overtone is an integer multiple of the fundamental. Since 264 Hz is not a multiple of 176 Hz, 176 Hz cannot be the fundamental, and so the pipe cannot be open. Thus it must be a closed pipe.

(b)  For a closed pipe, the successive overtones differ by twice the fundamental frequency. Thus 176 Hz must be twice the fundamental, so the fundamental is 88.0 Hz. This is verified since 264 Hz is 3 times the fundamental, 440 Hz is 5 times the fundamental, and 616 Hz is 7 times the fundamental.

ASSIGNMENT #9

Q11  The wave pattern created by standing waves does not “travel” from one place to another. The node locations are fixed in space. Any one point in the medium has the same amplitude at all times. Thus the interference can be described as “interference in space” — moving the observation point from one location to another changes the interference from constructive (anti-node) to destructive (node). To experience the full range from node to anti-node, the position of observation must change, but all observations could be made at the same time by a group of observers.

The wave pattern created by beats does travel from one place to another. Any one point in the medium will at one time have a 0 amplitude (node) and half a beat period later, have a maximum amplitude (anti-node). Thus the interference can be described as “interference in time”. To experience the full range from constructive interference to destructive interference, the time of observation must change, but all observations could be made at the same position.
Q14 From the two waves shown, it is seen that the frequency of beating is higher in Figure (a) — the beats occur more frequently. The beat frequency is the difference between the two component frequencies, and so since (a) has a higher beat frequency, the component frequencies are further apart in (a).

P40 The beat frequency is the difference in the two frequencies, or $277\text{ Hz} - 262\text{ Hz} = 15\text{ Hz}$. If the frequencies are both reduced by a factor of 4, then the difference between the two frequencies will also be reduced by a factor of 4, and so the beat frequency will be $\frac{1}{4}(15\text{ Hz}) = 3.75\text{ Hz} = 3.8\text{ Hz}$.

P44 Beats will be heard because the difference in the speed of sound for the two flutes will result in two different frequencies. We assume that the flute at $25.0^\circ\text{C}$ will accurately play the middle C.

$\begin{align*}
f_1 &= \frac{v_1}{2L} \rightarrow L = \frac{\frac{v_1}{2f_1}}{2(262\text{ Hz})} = 0.660\text{ m} \\
f_2 &= \frac{v_2}{2L} = \frac{\left[331 + 0.6(5.0)\right]\text{ m/s}}{2(0.660\text{ m})} = 253\text{ Hz} \quad \Delta f = 262\text{ Hz} - 253\text{ Hz} = 9\text{ beats/sec}
\end{align*}$

P45 Tuning fork A must have a frequency of 3 Hz either higher or lower than the 441 Hz fork B. Tuning fork C must have a frequency of 4 Hz either higher or lower than the 441 Hz fork B.

$\begin{align*}
f_A &= 438\text{ Hz or } 444\text{ Hz} \\
f_C &= 437\text{ Hz or } 445\text{ Hz}
\end{align*}$

The possible beat frequencies are found by subtracting all possible frequencies of A and C.

$|f_A - f_C| = 1\text{ Hz or } 7\text{ Hz}$

P83 For each pipe, the fundamental frequency is given by $f = \frac{v}{2L}$. Find the frequency of the shortest pipe.

$\begin{align*}
f &= \frac{v}{2L} = \frac{343\text{ m/s}}{2(2.40\text{ m})} = 71.46\text{ Hz}
\end{align*}$

The longer pipe has a lower frequency. Since the beat frequency is 11 Hz, the frequency of the longer pipe must be 60.46 Hz. Use that frequency to find the length of the longer pipe.

$\begin{align*}
f &= \frac{v}{2L} \rightarrow L = \frac{\frac{v}{2f}}{2(60.46\text{ Hz})} = 2.84\text{ m}
\end{align*}$
ASSIGNMENT #10

Q1 Huygens’ principle applies both to sound waves and water waves. Huygens’ principle applies to all waves that form a wave crest. Both sounds and water waves can be represented in this way.

Q3 There are certain situations where describing light as rays works well (for example, lenses) and there are other situations where describing light as waves works well (for example, diffraction). Actually, the ray model doesn’t work at all when describing diffraction. Thus, there are always limitations to the “models” we use to describe nature and we need to realize what these are.

Q4 The main reason that we can hear sounds around corners, but not see around corners, is diffraction. Sound waves have very long wavelengths when compared to light waves, which makes diffraction effects much more obvious. Diffraction effects are very noticeable once the size of the object that the wave is diffracting around is about the same size as the wavelength of the wave. The wavelength of sound is on the order of 1 m, while the wavelength of light is on the order of 0.1 µm. A secondary reason is reflection. Sounds waves reflect off of walls very well in a specular manner, and so can bounce around corners, but light reflects off of the walls in a very diffuse manner.

Q6 As red light is switched to blue light, the wavelength of the light is decreased. Thus, $d \sin \theta = m \lambda$ says that $\theta$ is decreased for a particular $m$ and $d$. This means that the bright spots on the screen are more closely packed together with blue light than with red light.

Q7 Destructive interference occurs when the path lengths of two rays of light from the same source differ by odd half-integers of the wavelength ($\lambda/2, 3\lambda/2, 5\lambda/2, (m + \frac{1}{2}) \lambda$, etc.). Under these conditions, the wave crests from one ray match up with the wave troughs from the other ray and cancellation occurs (destructive interference).

ASSIGNMENT #11

Q9 Similarities between doing a double-slit experiment with sound and light: the sources must be coherent for the interference pattern to be observed; they both produce a pattern of high and low intensity at some distance away from the double slit (bright and dark for the light and loud and quiet for the sound); they both work best with a single-frequency source. Differences between doing a double-slit experiment with sound and light: The slits for light must be extremely close together when compared to sound; you don’t actually need slits for sound (just use two speakers).

P1 For constructive interference, the path difference is a multiple of the wavelength: $d \sin \theta = m \lambda, m = 0, 1, 2, 3, \ldots$. For the fifth order, we have $(1.6 \times 10^{-5} \text{ m}) \sin 8.8^\circ = (5) \lambda$, which gives $\lambda = 4.90 \times 10^{-7} \text{ m}$. 
For constructive interference, the path difference is a multiple of the wavelength:
\[ d \sin \theta = m\lambda, \quad m = 0, 1, 2, 3, \ldots \]

For the third order, we have
\[ d \sin 18^\circ = (3)(610 \times 10^{-9} \text{ m}), \text{ which gives } d = 5.92 \times 10^{-6} \text{ m} \]

We find the location on the screen from
\[ x = L \tan \theta. \]
For small angles, we have
\[ \sin \theta \approx \tan \theta, \text{ which gives } \]
\[ x = L \left( \frac{m\lambda}{d} \right) = \frac{mL\lambda}{d}. \]

For adjacent fringes, \( \Delta m = 1 \), so we have
\[ \Delta x = \frac{L\lambda \Delta m}{d} ; \]
\[ = \frac{(3.6 \text{ m})(656 \times 10^{-9} \text{ m})(1)}{(0.060 \times 10^{-3} \text{ m})} = 3.94 \times 10^{-2} \text{ m} \]

With the new wavelength, then, the second-order maximum is located a distance of
\[ x = \frac{mL\lambda}{d} \]
\[ = \frac{(2)(1.6 \text{ m})(650 \times 10^{-9} \text{ m})}{2.0 \times 10^{-4} \text{ m}} = 0.0104 \text{ m} \text{ from the central maximum.} \]
\[ d \sin \theta = m\lambda, m = 0, 1, 2, 3, \ldots \]

We find the location on the screen from
\[ x = L \tan \theta. \]

For small angles, we have
\[ \sin \theta \approx \tan \theta, \text{ which gives} \]
\[ x = L \left( \frac{m\lambda}{d} \right) = \frac{mL\lambda}{d}. \]

For adjacent fringes, \( \Delta m = 1 \), so we have
\[ \Delta x = \frac{L\lambda\Delta m}{d} \]
\[ = \frac{(5.0 \text{ m})(544 \times 10^{-9} \text{ m})(1)}{1.0 \times 10^{-3} \text{ m}} = 2.72 \times 10^{-3} \text{ m}. \]

**ASSIGNMENT #12**

Q17. (a) When you increase the slit width in a single-slit diffraction experiment, the spacing of the fringes decreases. The equation for the location of the minima, \( a \sin \theta = m\lambda \), indicates that \( \theta \) is decreased for a particular \( m \) and \( \lambda \) when the width \( a \) increases. This means that the bright spots on the screen are more closely packed together for a wider slit.

(b) When you increase the wavelength of light used in a single-slit diffraction experiment, the spacing of the fringes increases. The equation for the location of the minima, \( a \sin \theta = m\lambda \), indicates that \( \theta \) is increased for a particular \( m \) and \( a \) when the wavelength increases. This means that the bright spots on the screen are spread further apart for a longer wavelength.

P17 We find the angle to the first minimum from
\[ a \sin \theta_{1\min} = m\lambda \Rightarrow \sin \theta_{1\min} = \frac{(1)(580 \times 10^{-9} \text{ m})}{(0.0440 \times 10^{-3} \text{ m})} = 0.0132, \text{ so } \theta_{1\min} = 0.755^\circ. \]

Thus the angular width of the central diffraction peak is
\[ \Delta \theta_i = 2\theta_{1\min} = 2(0.755^\circ) = 1.51^\circ. \]

P23 We find the angular half-width \( \theta \) of the central maximum from
\[ a \sin \theta = \lambda; \]
\[ \sin \left( \frac{55.0^\circ}{2} \right) = \frac{440 \times 10^{-9} \text{ m}}{a}, \text{ which gives } a = 9.53 \times 10^{-7} \text{ m}. \]

P24 We find the angle to the first minimum from the distances:
\[ \tan \theta_{1\min} = \frac{1}{2} \left( \frac{9.20 \text{ cm}}{255 \text{ cm}} \right) = 0.0180 = \sin \theta_{1\min}, \text{ because the angle is small.} \]
We find the slit width from
\[ a \sin \theta_{\text{min}} = m\lambda; \]
\[ a(0.0180) = (1)(415 \times 10^{-9} \text{ m}), \text{ which gives } a = 2.30 \times 10^{-5} \text{ m} = 0.0230 \text{ mm}. \]

P25 Because the angles are small, we have
\[ \tan \theta_{\text{min}} = \frac{1}{2} \left( \frac{\Delta x_1}{L} \right) = \sin \theta_{\text{min}}. \]
The condition for the first minimum is
\[ a \sin \theta_{\text{min}} = \frac{1}{2} a \frac{\Delta x_1}{L} = \lambda. \]
If we form the ratio of the expressions for the two wavelengths, we get
\[ \frac{\Delta x_{ib}}{\Delta x_{ia}} = \frac{\lambda_{ib}}{\lambda_{ia}}, \]
\[ \frac{\Delta x_{ib}}{(4.0 \text{ cm})} = \frac{(420 \text{ nm})}{(650 \text{ nm})}, \text{ which gives } \Delta x_{ib} = 2.58 \text{ cm}. \]

ASSIGNMENT #13

Q19 (a) The advantage of having many slits in a diffraction grating is that this makes the bright maxima in the interference pattern more sharply defined, brighter, and narrower.

(b) The advantage of having closely spaced slits in a diffraction grating is that this spreads out the bright maxima in the interference pattern and makes them easier to measure.

Q20 (a) The color at the top of the rainbow for the diffraction grating is violet. The equation \[ d \sin \theta = m\lambda, \] says that \( \theta \) is smallest (thus, the deviation from horizontal is smallest) for the shortest wavelength, for a given \( d \) and \( m \). The wavelength of violet light (450 nm) is shorter than that of red light (700 nm).

(b) The color at the top of a rainbow for the prism is red. The index of refraction for transparent materials (like the glass that makes up the prism) is smaller for long (red) wavelengths and larger for short (violet) wavelengths. Since the red light encounters a smaller index of refraction as it goes through the prism, it doesn’t slow as much as the violet light, which also means that it doesn’t bend as much as the violet. If the red light is bent away from the horizontal direction least, it will appear at the top of the rainbow.
We find the angle for the second order from
\[ d \sin \theta = m\lambda; \]
\[ (1.45 \times 10^{-5} \text{ m}) \sin \theta = (2)(560 \times 10^{-9} \text{ m}), \] which gives \( \sin \theta = 0.07722, \) so \( \theta = 4.43^\circ. \)

We find the wavelength from
\[ d \sin \theta = m\lambda; \]
\[ \left( \frac{1}{(3500 \text{ lines/cm})} \right) (10^{-2} \text{ m/cm}) \sin 28.0^\circ = 3\lambda, \] which gives \( \lambda = 4.47 \times 10^{-7} \text{ m} = 447 \text{ nm}. \)

We find the slit separation from
\[ d \sin \theta = m\lambda; \]
\[ d \sin 18.0^\circ = (3)(630 \times 10^{-9} \text{ m}), \] which gives \( d = 6.12 \times 10^{-6} \text{ m} = 6.12 \times 10^{-4} \text{ cm}. \)

The number of lines/cm is
\[ \frac{1}{d} = \frac{1}{(6.12 \times 10^{-4} \text{ cm})} = 1.64 \times 10^3 \text{ lines/cm}. \]

We find the angles for the second order from
\[ d \sin \theta = m\lambda \text{ with } m = 2. \]
\[ \frac{1}{6.0 \times 10^5 \text{ lines/m}} \sin \theta_1 = 2(7.0 \times 10^{-7} \text{ m}) \text{ gives } \sin \theta_1 = 0.84, \] so \( \theta_1 = 57.1^\circ. \)
\[ \frac{1}{6.0 \times 10^5 \text{ lines/m}} \sin \theta_2 = 2(4.5 \times 10^{-7} \text{ m}) \text{ gives } \sin \theta_2 = 0.54, \] so \( \theta_2 = 32.7^\circ. \)

Therefore, \( \Delta \theta = 57.14^\circ - 32.68^\circ = 24.5^\circ. \)

ASSIGNMENT #14

Q22 Once the thickness of the film becomes more than a few wavelengths thick, several interference patterns become mixed together, and it is hard to see any individual effects. When the thickness of the film is only about \( 1\lambda \) thick, then the reflections from the top and bottom surfaces of the film for each color have path differences of just one constructive interference (path difference = \( \lambda/2 \)) and one destructive interference (path difference = \( \lambda \)) patterns. It is easy for our eyes to pick out these widely spaced bright colors that are separated by dark areas on the film. Once the film gets very thick, though, there are many constructive (\( \lambda/2, 3\lambda/2, 5\lambda/2, \text{ etc.} \)) and many destructive (\( \lambda, 2\lambda, 3\lambda, \text{ etc.} \)) path differences allowed. The resulting interference patterns are all closely spaced and overlapping, making it difficult for our eyes to distinguish between the bright and dark areas. As the film gets even thicker, the larger amount of overlap causes all the colors to run together, making it impossible to see the individual interference patterns.
Q23  There are many, many circular tracks on a CD and each track is made up of a series of pits and high spots. Light reflects very well off of the high spots and not the low spots. Thus, when you shine white light on a CD, each track is a slightly different distance from you, and as the light reflects off of each track to you, they each have a different path length. Thus, you’ll basically see a colorful diffraction grating pattern. If a monochromatic light is used, you will see a single-color interference pattern. In other words, instead of seeing the full rainbow of colors spreading out from the center of the CD (as shown in Figure 24-56), there would just be several “spokes” of the same color as your source spreading out from the center of the CD. The spacings of these “spokes” can be used just like a diffraction grating to determine that the track spacing on the CD is approximately 1600 nm.

Q26 At the edge of the oil drop, the film is so thin that the path difference between the light reflecting off of the top surface and the light going through the oil and reflecting off of the bottom surface is so small that we can consider it to be zero. Thus, the two different rays of light must be in phase when they reach our eyes. We know that the phase of the light being reflected off of the top surface of the oil must have been flipped 180°, since the index of refraction of oil is greater than that of air. Thus, the reflection off of the bottom surface of the film (where it touches the water), must also have flipped the phase of the light 180°. This tells us that the index of refraction of the water is higher than that of the oil. Thus, we know that the index of refraction of the oil is greater than that of air and less than that of water: 1.00 < n < 1.33.

Q27 Polarization tells us that light is a transverse wave. Longitudinal waves cannot be polarized.

Q28 Polarized sunglasses completely (100%) block horizontally polarized glare and block all other polarizations of light 50%. Regular sunglasses just block 50-75% of all light coming in. The advantage of polarized sunglasses is the total elimination of glare. Even if regular sunglasses block a glare at 75%, the glare is so intense that it still makes it difficult for our eyes.

Q31 If Earth had no atmosphere, the “color” of the sky would be black (and dotted with stars and planets) at all times. This is the condition of the sky that the astronauts found on the Moon, which has no atmosphere. The reason the sky is blue for Earth, is that the air molecules scatter light from the Sun in all directions, and preferentially scatter blue light down to the surface. If there were no air molecules to scatter the light from the Sun, the only light we would see would be from the stars/planets and directly from the Sun and the rest would be black.
ASSIGNMENT #15

P70  The power output is found from the intensity, which is the power radiated per unit area.

\[ 105 \text{ dB} = 10 \log \frac{I}{I_0} \quad \Rightarrow \quad I = 10^{10.5} I_0 = 10^{10.5} \left(1.0 \times 10^{-12} \text{ W/m}^2\right) = 3.162 \times 10^{-2} \text{ W/m}^2 \]

\[ I = \frac{P}{A} = \frac{P}{4\pi r^2} \quad \Rightarrow \quad P = 4\pi r^2 I = 4\pi \left(12.0 \text{ m}\right)^2 \left(3.162 \times 10^{-2} \text{ W/m}^2\right) = 57.2 \text{ W} \]

P77  The frequency of the guitar string is to be the same as the third harmonic \( n = 3 \) of the closed tube.

The resonance frequencies of a closed tube are given by \( f_n = \frac{n v}{4 L} \), \( n = 1, 3, 5, \ldots \), and the frequency of a stretched string is given by \( f = \frac{1}{2L} \sqrt{\frac{F_T}{m/L}} \). Equate the two frequencies and solve for the tension.

\[ \frac{1}{2L_{\text{string}}} \sqrt{\frac{F_T}{m/L_{\text{string}}}} = \frac{3v}{4L_{\text{tube}}} \quad \Rightarrow \quad F_T = \frac{9v^2 m}{4L_{\text{string}}} = \frac{9 \left(343 \text{ m/s}\right)^2 \left(2.10 \times 10^{-3} \text{ kg}\right)}{4 \left(0.75 \text{ m}\right)} = 7.4 \times 10^2 \text{ N} \]

P80  The Doppler shift is 3.0 Hz, and the emitted frequency from both trains is 424 Hz. Thus the frequency received by the conductor on the stationary train is 427 Hz. Use this to find the moving train’s speed.

\[ f_o = f_s \left(\frac{v_{\text{sound}}}{v_{\text{source}} - v_{\text{source}}}\right) \quad \Rightarrow \quad v_{\text{source}} = \left(\frac{f_o - f_s}{f_o}\right) v_{\text{sound}} = \left(\frac{427 - 424 \text{ Hz}}{427 \text{ Hz}}\right) \left(345 \text{ m/s}\right) = 2.42 \text{ m/s} \]

P62  (a)  For constructive interference, the path difference is a multiple of the wavelength:

\[ d \sin \theta = m\lambda, \quad m = 0, 1, 2, 3, \ldots \]

We find the location on the screen from

\[ x = L \tan \theta. \]

For small angles, we have

\[ \sin \theta = \tan \theta, \quad \text{which gives} \]

\[ x = L \left(\frac{m\lambda}{d}\right) = \frac{mL\lambda}{d}. \]

For adjacent bands, \( \Delta m = 1 \), so we have

\[ \Delta x = \frac{L\lambda \Delta m}{d}; \]

\[ 2.0 \times 10^{-2} \text{ m} = \frac{(4.0 \text{ m})(5.0 \times 10^{-7} \text{ m})(1)}{d}, \quad \text{which gives} \quad d = 1.0 \times 10^{-4} \text{ m} = 0.10 \text{ mm}. \]

(b)  For destructive interference, the path difference is given by

\[ d \sin \theta = (m + \frac{1}{2})\lambda, \quad m = 0, 1, 2, 3, \ldots \]
Again we find the location on the screen from 
\[ x = L \tan \theta. \]

and again we use \( \sin \theta = \tan \theta \), this time to obtain 
\[ x = \frac{(m + \frac{1}{2})L\lambda}{d}. \]

We are told that 
\[ \frac{(5 + \frac{1}{2})L\lambda_2}{d} = \frac{(4 + \frac{1}{2})L\lambda_1}{d}, \]
\[ (5 + \frac{1}{2})\lambda_2 = (4 + \frac{1}{2})(5.0 \times 10^{-7} \text{ m}), \]
which gives \( \lambda_2 = 4.1 \times 10^{-7} \text{ m}. \)

P66 The wavelength of the signal is 
\[ \lambda + \frac{\nu}{f} = \frac{\left(3.00 \times 10^8 \text{ m/s}\right)}{\left(102.1 \times 10^6 \text{ Hz}\right)} = 2.94 \text{ m}. \]

Because measurements are made far from the antennae, we can use the analysis for the double slit. For constructive interference, the path difference is a multiple of the wavelength: 
\[ d \sin \theta = m\lambda, \quad m = 0, 1, 2, 3, \ldots; \]
\[(8.0 \text{ m}) \sin \theta_{1\text{max}} = (1)(2.94 \text{ m}), \quad \text{which gives } \theta_{1\text{max}} = 22^\circ; \]
\[(8.0 \text{ m}) \sin \theta_{2\text{max}} = (2)(2.94 \text{ m}), \quad \text{which gives } \theta_{2\text{max}} = 47^\circ; \]
\[(8.0 \text{ m}) \sin \theta_{3\text{max}} = (3)(2.94 \text{ m}), \quad \text{which gives } \sin \theta_{3\text{max}} > 1, \text{ so there is no third maximum.} \]

For destructive interference, the path difference is an odd multiple of half a wavelength: 
\[ d \sin \theta = (m + \frac{1}{2})\lambda, \quad m = 0, 1, 2, 3, \ldots; \text{ or} \]
\[(8.0 \text{ m}) \sin \theta_{1\text{min}} = (0 + \frac{1}{2})(2.94 \text{ m}), \quad \text{which gives } \theta_{1\text{min}} = 11^\circ; \]
\[(8.0 \text{ m}) \sin \theta_{2\text{min}} = (1 + \frac{1}{2})(2.94 \text{ m}), \quad \text{which gives } \theta_{2\text{min}} = 33^\circ; \quad \text{or} \]
\[(8.0 \text{ m}) \sin \theta_{3\text{min}} = (2 + \frac{1}{2})(2.94 \text{ m}), \quad \text{which gives } \theta_{3\text{min}} = 67^\circ; \]
\[(8.0 \text{ m}) \sin \theta_{4\text{min}} = (3 + \frac{1}{2})(2.94 \text{ m}), \quad \text{which gives } \sin \theta_{4\text{min}} > 1, \text{ so there is no fourth minimum.} \]
We find the angles for the first order from the distances:

\[ \tan \theta_1 = \frac{x_1}{L} = \frac{3.32 \text{ cm}}{60.0 \text{ cm}} = 0.0553, \text{ so } \theta_1 = 3.17^\circ; \]

\[ \tan \theta_2 = \frac{x_2}{L} = \frac{3.71 \text{ cm}}{60.0 \text{ cm}} = 0.0618, \text{ so } \theta_2 = 3.54^\circ. \]

We find the separation of lines from

\[ d \sin \theta = m\lambda; \]

\[ d \sin 3.17^\circ = (1)\left(589 \times 10^{-9} \text{ m}\right), \text{ which gives } d = 1.066 \times 10^{-5} \text{ m} = 1.066 \times 10^{-3} \text{ cm}. \]

For the second wavelength we have

\[ d \sin \theta_2 = m\lambda_2; \]

\[ (1.06 \times 10^{-5} \text{ m}) \sin 3.54^\circ = (1)\lambda_2, \text{ which gives } \lambda_2 = 6.58 \times 10^{-7} \text{ m} = 658 \text{ nm}. \]

The number of lines/cm is

\[ \frac{1}{d} = \frac{1}{(1.066 \times 10^{-3} \text{ cm})} = 938 \text{ lines/cm}. \]